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WATER USE EFFICIENCY AND RAIN WATER PRODUCTIVITY OF WHEAT UNDER VARIOUS TILLAGE-GLYPHOSATE INTERACTIVE SYSTEMS

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ABSTRACT. Rainfed wheat is generally grown in rotation with summer fallow in medium to high rainfall zone of Pothwar plateau of Pakistan. The present study was, therefore, conducted to investigate the impact of shallow and deep tillage practices, with and without herbicide (glyphosate) application, on moisture conservation and subsequent wheat yields. The study also aimed to examine the feasibility of substituting intensive shallow tillage with single application of glyphosate. The experiment was laid out in randomized complete block design with three replicates and net plot size of 14 m x 10 m, during 2007 and 2008 at two locations i.e high and medium rainfall. Wheat cultivar "GA-2002" was planted as a test crop. The data showed the superiority of conservation tillage in terms of conservation of moisture and increasing grain yields. Results also elaborated that tillage cannot be completely eliminated for profitable fallow management. However, deep ploughing with moldboard followed by single application of glyphosate proved potential option for substituting shallow tillage carried out during summer (kharif). The additional benefits under this tillage system included saving in fuel, labour and lower depreciation and maintenance costs for tillage machinery in addition to unquantifiable environmental benefits.

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Key words: Wheat; Water use efficiency; Tillage; Glyphosate; Wheat yield.

INTRODUCTION

The Pothwar plateau of Pakistan lies between latitude 32.17^o to 34.15^{o}N and longitude 71.17^o to 73.92^{o}E. Agricultural production in the region is mainly rainfed which provide food security to the inhabitants and of paramount importance to the national economy. Wheat (*Triticum aestivum* L.) being the staple food crop is grown on vast area. During the year 2006-'07, it was grown over an area of 8.494 million hectare resulting in total production of 23.52 million tonnes with an average yield of 2769 kg ha^{-1} in the region. The average wheat yield during dry years varied ranging from 500 to 600 kg ha^{-1} and 1400 to 1900 kg ha^{-1} during wet years (GOP, 2006-'07).

The precipitation during the wheat growing season is usually insufficient to sustain adequate crop growth without conserving soil moisture in the preceding monsoon season. The crop yield is reduced by moisture deficit on account of high evaporation demands, which often exceeds precipitation. The rainfall pattern offers huge potential for *in situ* soil moisture conservation as 60 -70 % of the annual rainfall is received during summer as high intensity rainstorms. The soil moisture can substantially be increased by retaining all the incident rainfall right in the field for increased absorption in the root zone (Hobbs, 1961; Tomar *et al.,* 1978). This can be achieved through several management strategies such as adding organic matter, spreading mulch, through tillage practices and growing various cover crops. Tillage is the only practicable and viable option to achieve higher water use efficiency and crop productivity in the region through in situ conservation of monsoon rainwater to harvest better wheat yields in the subsequent season (SAWCRI, 2006). Similarly, Ahmad *et al*. (1996) reported that tillage plays a key role and contributed 5-20% to crop productivity in Pakistan.

The traditional tillage system in Pothwar tract of Pakistan is used as mechanical weed control practice during the fallow period. Major part of the land in rainfed areas, is tilled by cultivator which generally breaks the soil surface to less than 10 cm depth. The continued tillage with same plough for years after years at the same depth resulted in the formation of plough pans of varying hardness and thickness between 10 and 30 cm depth. The research during eighties recognized the superiority of deep tillage, over the traditional shallow tillage, in enhancing wheat productivity in Pothwar (BARD, 1987; Hobbs *et al*., 1986). The deep tillage at the onset of monsoon rains has been found essential, every year, for optimum moisture conservation and wheat productivity (Rashid *et al*., 2004).

It has been reported that repeated shallow tillage is reducing wheat profitability on account of ever increasing hike in fuel cost. One potential option is to eliminate shallow tillage operations carried out during fallow period. If tillage is eliminated from a management program in a cereal or corn crop, control of grass weeds may be limited to direct applications of non-selective herbicides such as paraquat and glyphosate prior to sowing because these deplete soil moisture and nutrients, otherwise (Locke *et al.,*2002).

The study of resource conserving practices is essential if the farming community of rainfed areas is to deal with the moisture deficit, rising energy costs, the demands of exploding populations and economic challenges. The integration of tillage practices with chemical weed control (glyphosate) may help in sustaining soil productivity, improving water conservation, maintaining good yields and decreasing weed crop losses. Therefore, the present study has been designed to evaluate the impact of different deep and shallow tillage practices with and without herbicide application on water use efficiency, rain water productivity and subsequent wheat yield under rainfed conditions of Pothwar plateau with semi-arid climate.

MATERIALS AND METHODS

The proposed study was conducted at the experimental farm, Pir Mehr Ali Shah, Arid Agriculture University, Rawalpindi (high rainfall, >800 mm annually) and Barani Agriculture Research Institute, Chakwal (Pakistan) (medium rainfall, <500 mm annually), during 2007-'08 and 2008-'09 (*Fig.1 - a,b*). The experiment was carried out in a randomized complete block design (RCBD), consisting of nine tillage treatments with three replicates. The net plot size was 14 m x 10 m with a 1 m buffer zone between plots and a 4 m buffer zone between the blocks. A wheat-fallow rotation was established during the course of study. The data regarding soil physico-chemical properties at both sites are presented in *Table 1*.

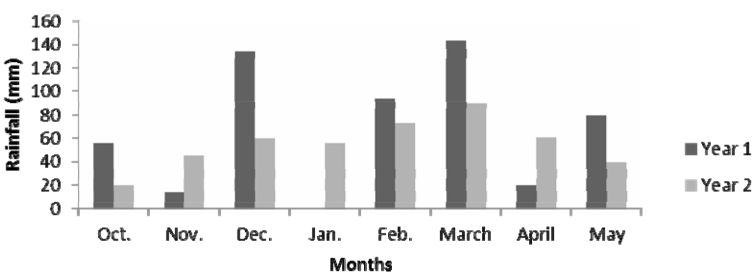

Figure 1a – Monthly rainfall (mm) during 2007-'08 and 2008-'09 at Rawalpindi

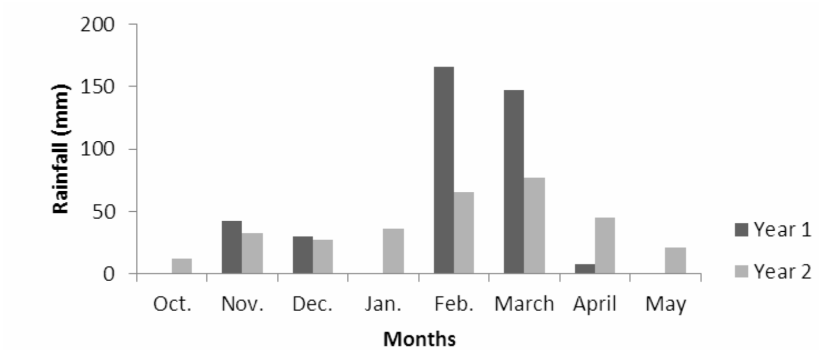

Figure 1b – Monthly rainfall (mm) during 2007-'08 and 2008-'09 at Chakwal

Table 1 - Physico-chemical properties of experimental sites during 2007-'08 and 2008-'09

Characteristics	Rawalpindi (High rainfall zone)		Chakwal (Medium rainfall zone)	
	2007-'08	2008-'09	2007-'08	2008-'09
Textural class	Loam	Loam	Sandy Loam	Sandy Loam
pH	7.60	7.30	7.7	7.7
Organic matter	5.5 g kg^{-1}	4.9 g kg^{-1}	4.6 g kg^{-1}	4.1 g kg^{-1}
Total nitrogen	0.068	0.051	0.050	0.033
Available phosphorus	5.0 mg kg^{-1}	4.49 mg kg^{1}	4.7 mg kg^{-1}	4.1 mg kg^{-1}
Extractable potassium	99 mg kg^{-1}	82 mg kg^{-1}	88 mg kg^{-1}	71 mg kg^{-1}

Wheat cultivar GA-2002 was used as a test crop. Sowing was done in the 2nd week of November 2007 and in 1st week of 2008 at Rawalpindi, while at Chakwal sowing was carried out in 3rd week of November, 2007 and 2nd week of November 2008. The crop was sown at the rate of 110 kg ha^{-1} with the help of an automatic rabi drill. Recommended cultural practices, as proposed by Shah (1994), were adopted for all the treatments. The fertilizer NPK was applied at the rate of 110, 80 kg ha^{-1} and 60 kg ha^{-1}. NPK was applied in the form of urea, DAP (Diammonium phosphate) and potassium sulphate, respectively. Crop was harvested manually at physiological maturity. Threshing of each plot was done separately.

The experiment consisted of following treatments: 1. Weedy check (W); 2. Conventional tillage (CT); 3. Moldboard plough + shallow tillage after every effective rainfall, i.e. >12mm (MB+C); 4. Moldboard plough + preparatory tillage (MB); 5. Moldboard plough + glyphosate + preparatory tillage (MB+H); 6. Chisel ploughing + preparatory tillage (CP); 7. Chisel plough + glyphosate + preparatory tillage (CP+H); 8. Disc plough + preparatory tillage (DP); 9. Disc Plough + glyphosate + preparatory tillage (DP+H)

Conventional tillage involved primary and secondary tillage operations with traditional tractor driven cultivator. In treatment No. 3, shallow tillage also meant cultivation by cultivator. In rest of the treatments, respective ploughing by moldboard, chisel and disc ploughs was carried out during June of both years at Rawalpindi and Chakwal, respectively, with no subsequent tillage during the kharif season. The experimental field contained wheat stubbles of 10-15 cm length prior to primary tillage operations. Tillage treatments involving herbicide were applied with glyphosate at the rate of 2 L ha^{-1} during 3rd week of August 2007 and 2nd week of August 2008 at both locations to control weeds and minimize weeds competition, especially for soil moisture. All the treatment plots were bunded to ensure zero runoff. Data was analyzed statistically by using Fishers analysis of variance technique and least significant test at 5% probability level was used to compare treatment means (Steel *et al*., 1997)

Water use and water use efficiency (WUE) calculations

Soil samples were collected up to a depth of 120 cm (with an interval of 15 cm to 30 cm) at the time of wheat sowing and at harvest to determine water use and water use efficiency. Then water use efficiency was calculated with the help of following formula:

$$\text{Water use efficiency} = \frac{\text{Grain yield}\left(\text{kg ha}^{-1}\right)}{\text{Water use (mm)}}$$

Water use was calculated as rainfall plus the difference in water content between wheat crop maturity and sowing (Chen *et al*. 2003). Water use is commonly expressed in terms of total water supply, i.e. rain or transpiration plus soil evaporation (Bolton, 1991; Cooper *et al*. 1987). Runoff was assumed to be negligible in the calculation because the experiment will be conducted on relatively level (< 1% slope) ground (Chen *et al*. 2003). Drainage from the root zone during the wheat growing season was also assumed to be negligible because gentle rain showers are received during wheat growing season.

Rainfall use efficiency (RUE) was calculated according to Oweis (1997) by dividing wheat grain yield by growing season precipitation (October to April) as:

$$\text{Rainfall use efficiency} = \frac{\text{Wheat yield}\left(\text{kg ha}^{-1}\right)}{\text{Rainfall (mm)}}$$

RESULTS

Dry weed biomass (g m^{-2})

The differential response among various tillage systems to weed biomass at both locations is presented (*Fig. 2*). The weed biomass varied from 29.58-90.51 g m^{-2} and 11.0-72.4 g m^{-2} in different treatments at Rawalpindi and Chakwal, respectively. At Rawalpindi, the highest weed biomass of 90.51 g m^{-2} was recorded in weedy plots. The lowest weed biomass yield of 29.58 gm^{-2} was recorded in mouldboard+cultivator treatment. It was followed by mouldboard + herbicide application at the same location. Similarly at Chakwal, the lowest weed biomass of 11 g m^{-2} was recorded in plots where mouldboard plough was used and shallow tillage was done after every rainfall. It was followed by mouldboard+herbicide treatment. The statistically significant differences among various deep and shallow tillage systems for dry weed biomass yield at harvest (*Fig. 2*).

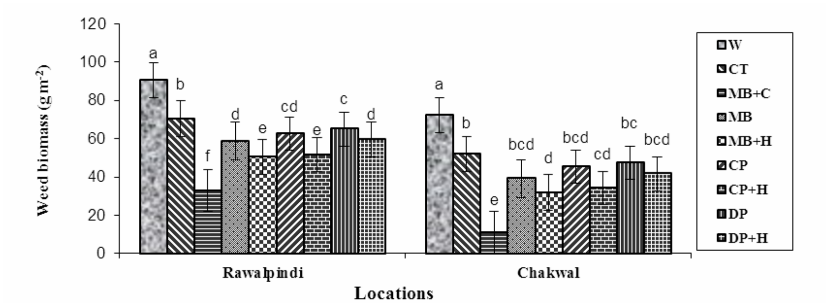

Figure 2 – Dry weed biomass (g m^{-2}) as influenced by different tillage system (pooled over years)

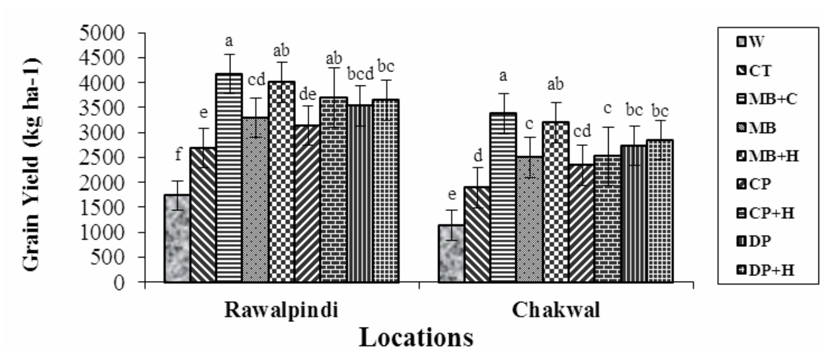

Figure 3 – Grain yield (kg ha^{-1}) as influenced by different tillage systems (pooled over years)

Grain yield (kg ha^{-1})

Grain yield is an interplay of yield components, especially 1000-grain weight. Moreover, final grain yield greatly depends upon seasonal availability of moisture. Under rainfed conditions moisture is of great significance. The data presented in (*Fig. 3*) illustrated the effect of various tillage practices with and without herbicide application on grain yield of wheat. The highest grain yield of 4170 kg ha^{-1} was recorded with mouldboard+tillage with cultivator after every effective rainfall (MB+C) treatment at Rawalpindi. It was at par with mouldboard+herbicide treated plots at the same location. Among the other promising tillage practices disc plough with and without herbicide provided better grain yield, compared to rest of treatments. The lowest grain yield of 1738 kg ha^{-1} at this location was recorded in weedy plots.

At Chakwal, the highest grain yield of 3374 kg ha^{-1} was recorded in MB+C treatment. It was at par with MB+H treatment that produced grain yield of 3203 kg ha^{-1}. The CP+H treatment produced grain yield of 2531 kg ha^{-1}, it was statistically significant from MB+C (3374 kg ha^{-1}) and MB+H (3202 kg ha^{-1}) treatments, however the later two treatments were at par with DP and DP+H treatments yielding 2735 and 2851 kg ha^{-1} of grain yield, respectively. The grain yield in conventional tillage treatment was 1894 kg ha^{-1}. The lowest grain yield of 1141 kg ha^{-1} was recorded in weedy treatment.

Water use and water use efficiency (WUE)

Water is the limiting factor in arid and semi arid tropical agriculture. Therefore, water use is an important indicator of the efficiency of any tillage system. Data revealed that water use varied from 451-572 mm and 403.9-554.0 mm in different tillage treatments at Rawalpindi and Chakwal, respectively. Maximum water use (572 mm) at Rawalpindi was recorded in disc plough treatment. While the minimum water use (451mm) was recorded in weedy plots at the same location. At Chakwal, maximum water use (554 mm) was recorded in DP treatment followed by MB+C treatment (531 mm). The minimum water use was noted in MB treatment. Among tillage-herbicide integrated treatments, the efficiency of MB+H was higher, where water use was 425.9 mm. The water use in MB+H treatment was only 12 mm higher than weedy plot but 55 mm lower than conventional tillage.

Maximizing water use efficiency is an important issue for semi-arid land tropics (Gregory, 1989). The data presented in *Fig. 4* showed differential response of various tillage practices for water use efficiency at both locations. The highest water use efficiency of 8.9 kg ha^{-1} mm^{-1} was recorded in mouldboard treatment with herbicide application and preparatory tillage at Rawalpindi. It was followed by mouldboard+tillage with cultivator after every effective rainfall. The lowest water use efficiency of 3.85 kg ha^{-1} mm^{-1} was recorded in weedy plots at this location.

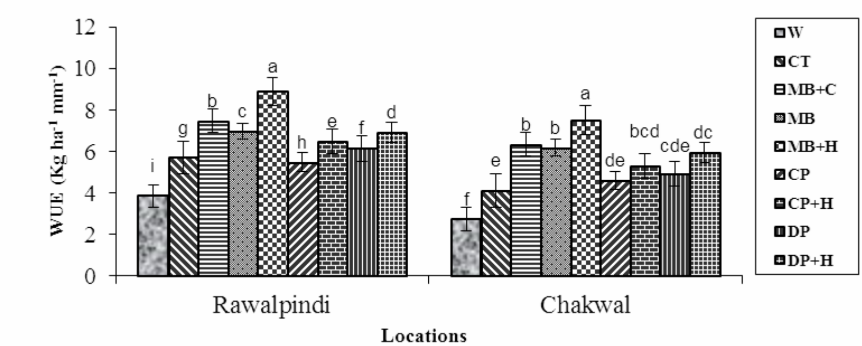

Figure 4 – Watter use efficiency as influenced by different tillage systems (pooled over years)

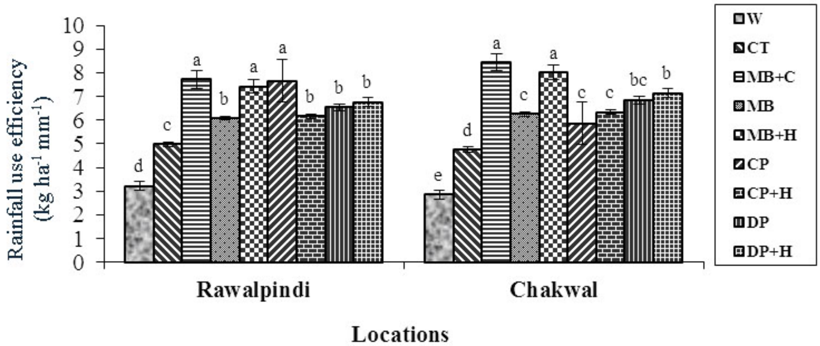

Figure 5 – Rainfall use efficiency (kg ha^{-1} mm^{-1}) as influenced by different tillage systems (pooled over years)

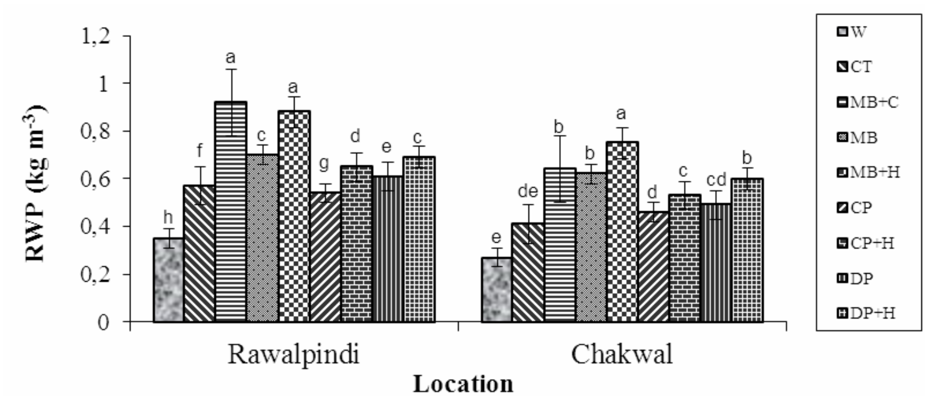

Figure 6 – Rainwatter productivity as influenced by different tillage systems (pooled over years)

At Chakwal, higher WUE with mouldboard was recorded and it ranged from 6.18 to 7.52 kg ha^{-1} mm^{-1}. In disc plough and chisel plough treatment WUE ranged from 4.60 to 5.96 kg ha^{-1} mm^{-1}. However, it is noticeable that higher WUE of 4.52 kg ha^{-1} mm^{-1} in MB+H treatment was not only due to higher wheat grain yield but lower water use compared to other deep, shallow and reduced tillage practices. The lowest WUE (2.74 kg ha^{-1} mm^{-1}) was recorded in weedy plot.

Rainfall use efficiency (RUE)

Data presented (*Fig. 5*) revealed that rainfall use efficiency under different tillage treatments differed significantly. It varied from 3.21 to 7.71 kg ha^{-1} mm^{-1} and 2.85 to 8.44 kg ha^{-1} mm^{-1} at Rawalpindi and Chakwal, respectively. The highest RUE was recorded with MB+C treatment at Rawalpindi. It is a practice used by progressive growers under rainfed conditions.

The data further revealed that at Chakwal MB plough had highest rain use efficiency (8.01-8.44 kg ha^{-1} mm^{-1}) whether, followed by shallow tillage or by herbicide application (glyphosate). MB alone had lower efficiency (6.25 kg ha^{-1} mm^{-1}) than other MB treatments. The rain use efficiency was also low under reduced tillage treatments (CP, CP+H), however, DP+H had comparatively better rainfall use efficiency of 7.13 kg ha^{-1} mm^{-1}. The rain use efficiency was lower (4.74 kg ha^{-1} mm^{-1}) under conventional tillage and least (2.85 kg ha^{-1} mm^{-1}) under weedy check at this location.

Rainwater productivity (RWP)

The perusal of the data presented in *Fig. 6* indicated significant differences for rainwater productivity at both locations being maximum at Rawalpindi. The highest RWP (0.92 kg m^{-3}) at this location was recorded with mouldboard where cultivator was used after every effective rainfall i.e. >12 mm. It was followed by MB+H treatment at the same location. The lowest rainwater productivity of 0.35 kg m^{-3} was recorded in weedy plots.

Similarly at Chakwal, the highest rainwater productivity of 0.75 kg m^{-3} was achieved in MB+H treatment pointing out it as a very efficient system under rainfed conditions. Over all mouldboard application gave better results as RWP ranged between 0.62-0.75 kg m^{-3} under different MB treatments. In CP and DP treatments RWP varied from 0.46 to 0.60 kg m^{-3}. Again the lowest rainwater productivity of 0.27 kg m^{-3} was recorded in weedy plots.

DISCUSSION

Sustainable agriculture in dryland areas of Pothwar aims at management and conservation of natural resources (water and soil) accompanied with a steady and substantial increase in crop yield. The results of the study regarding use of deep and shallow tillage practices for increasing yield and conservation of natural resources showed differential response of various tillage systems regarding weed biomass yield at both locations. The biomass was reduced by 118 % and 28 % in conventional tillage (CT) in comparison to weedy at Rawalpindi and Chakwal, respectively. At Chakwal, the MB+C treatment produced lowest biomass of 11.0 g m^{-2} showing maximum control over weeds (85%); however, it involved intensive tillage during the entire fallow period. Similar trends were observed at Rawalpindi, where the lowest weed biomass yield was recorded in MB+C treatment. It may be attributed to the fact that tillage with cultivator after every effective rainfall (>12 mm) uprooted weeds, which, ultimately, led to weed suppression resulting in lowest weed biomass yield in these treatments. Encouraging results were also noticed in MB+H treatment, in which biomass was reduced from 90.51 to 50.51 g m^{-2} and 72.37 to 31.93 g m^{-2} than weedy at Rawalpindi and Chakwal, respectively. The weed biomass recorded in this (MB+H) treatment was significantly different from conventional tillage and weedy plots at both locations. Johnson grass (*Sorghum halepense*) was the predominant weed in the experimental field at Chakwal. While at Rawalpindi, *Cyperus rotundus, Digera arvensis, Convalvulous arvensis, Cynodon dactylon* and *Sorghum halepense* were the most dominating weeds.

The data further illustrated that the efficiency of MB plough alone or integrated with the glyphosate was significantly higher than chisel or disc plough treatments for weed biomass yield at Rawalpindi. At Chakwal, though there was reduction in weed biomass in these tillage treatments, however, it was not significantly different from MB plough treatments. The results are in accordance with the findings of Froud-Williams *et al.* (1983), who reported that inversion tillage such as MB ploughing resulted in burial of a large proportion of seed in the tillage layer whereas, non-inversion tillage methods such as chisel ploughing left greater proportion of seed near the soil surface, that resulted into the germination and development of these noxious plants.

The results pertaining grain yield indicated that grain yield in wheat-fallow rotation were higher under deep and reduced tillage treatments than shallow tilled and weedy plots. The yield recorded from MB+C was at par with MB+H and CP+H treatment at Rawalpindi, which favours the view that intensive shallow tillage operations during kharif season can safely be substituted with deep tillage+application of glyphosate. Other tillage-herbicide integrated systems though produced higher yields than conventional tillage, but lesser than MB+H and CP+H at this location. The results also revealed that if weeds were allowed to establish during fallow period as in case of weedy check treatment, these caused reduction in wheat yield by 58% at Rawalpindi and 66% at Chakwal, compared to MB+C treatment during the subsequent season. The higher wheat yields in MB+C or MB+H treatments was due to more number of grains spike^{-1}, higher 1000-grain weight and higher number of tillers per unit area at both locations. The deep tillage treatment appeared to have loosened soil, lowered bulk density, reduced weed biomass yield, increased cumulative infiltration; hence, soil conserved more moisture and, ultimately, led to higher wheat yields. The results are in agreement with the findings of Rashid *et al.* (2004), who reported that deep ploughing loosened soil, increased infiltration during rainfall, enhanced root penetration and increased yield significantly.

The water use is the primary factor for yield differences in various tillage treatments, as it has key role in production and utilization of photosynthates, which help the plants in producing better yields. The higher water use translated directly into higher grain yield in respective treatments and vice versa. Similarly, the value of water use efficiency under conventional tillage was drastically low among tillage treatments, depicting the inferiority of such tillage in comparison to deep tillage practices in rainfed areas of Pothwar plateau of Pakistan. The results are in accordance with the findings of Ali (1998), who reported that deep tillage had significant effect on water use efficiency as compared to zero tillage.

The results are also in agreement with the findings of Du *et al*. (2000), who recorded 13% higher WUE under conservation tillage for winter wheat in comparison to conventional tillage. However the data is in contrast to the findings of Mrabet (2000), who could not find any significant difference in WUE among different shallow, minimum and deep tillage treatments.

Rainfall use efficiency being the ratio of wheat grain yield to rainfall received during the crop growth period depicts the efficiency of rain utilization, ignoring the fact of stored water from the preceding season. The possible reason of higher rain use efficiency under deep tillage vs weedy check may be attributed to the fact that tillage increases water holding and transmitting properties of the soil (Elwell, 1993). However, it is worth mentioning that in higher rainfall use efficiency, the main contributor is the grain yield and not the rainfall, as it is constant in all the tillage treatment.

Grain yield as a proportion of the total volumetric water use known as rain water productivity. The data in *Fig. 5* exhibited almost similar trend as was observed in water use efficiency. At Rawalpindi, the highest rain water productivity of 0.92 kg m^{-3} was recorded in MB+C treatment. While at Chakwal, MB+H treatment was at the top with the highest rainwater productivity of 0.75 kg m^{-3}. It meant that deep tillage with herbicide application was highly efficient in term of water use. In general, water productivity was higher under MB treatments than rest of the tillage systems tested, i.e. chisel plough, disc plough etc. Conventional tillage was not very efficient in terms of water productivity. The lowest water productivity was recorded in weedy plots indicating highly inefficient system in terms of productivity of economic parts per unit of water use.

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